

Executive Summary of the NASA Ames Research Center Heliophysics Small/Nano-Sats Working Group

The Ames Research Center Heliophysics Small-Sat/Nano-Sat Working Group was chartered to develop a strategy to exploit the growing capabilities of small satellites and nano-satellites to address Living with a Star (LWS) system science goals. The working group identified knowledge and measurement gaps in the study of the LWS system that could be filled using small-sat and nano-sat missions, outlined example missions with the potential to address these gaps, and identified relevant technologies. Expertise for the study was drawn from both the LWS science community and the nano-sat/small-sat development community.

The NASA Heliophysics/LWS program studies the interaction between the variable sun, the Earth and the solar system. This program, by necessity, deals with the complexity of a connected system that requires multiple, distributed measurement perspectives to provide the necessary scientific data in order to understand and model the diversity of physical couplings involved.

The LWS program charts an exciting and challenging research plan, with overarching goals to understand the solar outputs that drive the solar system and earth environment, and the responses of those environments (e.g. radiation environments and the planetary response via magnetospheric/ionospheric coupling). The goals of the program are outlined in multiple documents, including the Heliophysics Decadal Survey, the Heliophysics Roadmap, the 2015 COSPAR/ILWS roadmap, and the Living With a Star Program 10-Year Vision Beyond 2015. Multiple spacecraft currently contribute to this system study, including many in their extended mission phase. This understanding should enable us to forecast space weather and to map its impacts on technological infrastructure in space and on earth.

The pursuit of these important goals often requires distributed measurements or measurements from multiple perspectives such as THEMIS/ARTEMIS, STEREO, ACE and others. The development and deployment of traditional multiple spacecraft missions to address such measurements tend to be expensive, thereby limiting the rate at which progress can be made. In recent years, however, there has been a rapid development in the capabilities of nano-spacecraft, driven by the frequent access to space available to nano-sats that comply with the CubeSat standard, and investment in small-sat and nano-sat technologies. CubeSats have evolved to be capable of sophisticated measurements, and to have architectures capable of collecting and returning significant amounts of data. Additionally, standardized small spacecraft buses (e.g. compatible with the EELV Secondary Payload Adaptor or ESPA-ring) are becoming more capable

and affordable. These new, cost effective platforms have the potential to provide new tools to address significant LWS science goals.

The study team reviewed the breadth of the LWS science domain and found that the use of nano-sat/small-sat technologies and launch opportunities would provide significant value in the study of the LWS system. An initial assessment of science requirements from the perspective of available and anticipated technologies led the team to conclude that the following general mission criteria would provide the best utility to exploit the identified LWS system science: individual 6U to 12U CubeSats and larger small-sats both for in-situ measurements and for solar, magnetospheric, ionospheric-thermospheric-mesospheric remote sensing; several goals that benefit from swarms or constellations with at least 6 S/C, up to 60 S/C, (with some of these potentially launched sequentially); data rates from 1 kb/s upward; orbits from LEO to interplanetary; S/C propulsion for prime-phase orbit maintenance and adjustment; attitude stability for remote sensing better than 10"/minute.

The study team concluded the following:

- 1) LWS system science has a critical need to use cubesat/smallsat technologies and launch opportunities to enable essential in-situ and remote-sensing measurements in key regions in the Sun-Earth domain. These could be single-point measurements in uncovered critical regions, or distributed multi-point and multi-orbit measurements to better characterize the Sun-Earth and Sun-Solar systems.
- 2) LWS system science will benefit from both standalone cubesat/smallsat missions and also missions that provide critical contextual and complementary measurements to existing heliophysics missions.
- 3) Many heliophysics mission concepts enabled by cubesat/smallsat capabilities consist of either swarms or constellations from 6 S/C up to 60 S/C small-sats. Consequently, many of these missions are not "small" in their class (perhaps up to $\sim 1/2$ as large as a typical SMEX mission), however, they benefit from technologies emerging from the cubesat realm, and their capability for a given cost is substantial.
- 4) For multi-spacecraft missions or missions where small-sats and nano-sats augment existing assets, there would be significant utility in considering cost benefit and risk relative to the performance of the larger constellation, rather than the functionality/risk of each of the component S/C.
- 5) We recommend that the rapidly advancing capabilities of, and opportunities for, cubesats and smallsats be studied as part of our mission portfolio, broadening the range of tools we have to address LWS system science goals.